

COMBINATORIAL STRATEGIES FOR POLYMER SYNTHESIS

Ins → ADI BACKGROUND OF THE INVENTION

5 This application is a continuation-in-part of U.S. Serial No. 796,243 (filed November 22, 1991) which is incorporated herein by reference for all purposes. This application is also a continuation-in-part of U.S. Serial No. 874,849 (filed April 24, 1992), which is incorporated herein by reference for all purposes.

10 The present invention relates to the field of polymer synthesis and screening. More specifically, in one embodiment the invention provides an improved method and system for synthesizing arrays of diverse polymer sequences. According to a specific aspect of the invention, a method of synthesizing diverse polymer sequences such as peptides or oligonucleotides is provided. The diverse polymer sequences may be used, for example, in screening studies for determination of binding affinity.

15 Methods of synthesizing desired polymer sequences such as peptide sequences are well known to those of skill in the art. Methods of synthesizing oligonucleotides are found in, for example, Oligonucleotide Synthesis: A Practical Approach, Gate, ed., IRL Press, Oxford (1984), incorporated herein by reference in its entirety for all purposes. The so-called "Merrifield" solid phase peptide synthesis has been in common use for several years and is described in Merrifield, J. Am. Chem. Soc. (1963) 85:2149-2154, incorporated herein by reference for all purposes. Solid-phase synthesis techniques have been provided for the synthesis of several peptide sequences on, for example, a number of "pins." See e.g., Geysen et al., J. Immun. Meth. (1987) 102:259-274, incorporated herein by reference for all purposes. Other solid-phase techniques involve, for example, synthesis of various peptide sequences on different cellulose disks supported in a column. See Frank and Doring, Tetrahedron (1988) 44:6031-6040, incorporated herein by reference for all purposes. Still other solid-phase techniques are described in U.S. Patent No. 4,728,502 issued to Hamill and WO 90/00626 (Beattie, inventor).

20 Each of the above techniques produces only a relatively low density array of polymers. For example, the technique described in Geysen et al. is limited to producing 96 different polymers on pins spaced in the dimensions of a standard microtiter plate.

25 Improved methods of forming large arrays of peptides, oligonucleotides, and other polymer sequences in a short period of time have been devised. Of particular note, Pirrung et al., U.S. Patent No. 5,143,854 (see also PCT Application No. WO 90/15070) and Fodor et al., PCT Publication No. W 92/10092, all incorporated herein by reference, disclose methods of forming vast arrays of

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peptides and other polymer sequences using, for example, light-directed synthesis techniques. See also, Fodor et al., Science (1991) 251:767-777, also incorporated herein by reference for all purposes.

5 Some work has been done to automate synthesis of polymer arrays. For example, Southern, PCT Application No. WO 89/10977 describes the use of a conventional pen plotter to deposit three different monomers at twelve distinct locations on a substrate. These monomers were subsequently reacted to form three different
10 polymers, each twelve monomers in length. The Southern Application also mentions the possibility of using an ink-jet printer to deposit monomers on a substrate. Further, in the above-referenced Fodor et al., PCT application, an elegant method is described for using a computer-controlled system to direct a VLSIPS™ procedure. Using this
15 approach, one heterogenous array of polymers is converted, through simultaneous coupling at a number of reaction sites, into a different heterogenous array. This approach is referred to generally as a "combinatorial" synthesis.

 The VLSIPS™ techniques have met with substantial success.
20 However, in some cases it is desirable to have alternate/additional methods of forming polymer sequences which would not utilize, for example, light as an activator, or which would not utilize light exclusively.

25 SUMMARY OF THE INVENTION

 Methods and devices for synthesizing high-density arrays of diverse polymer sequences such as diverse peptides and oligonucleotides are provided by virtue of the present invention. In addition, methods and devices for delivering (and, in some cases,
30 immobilizing) available libraries of compounds on specific regions of a substrate are provided by this invention. In preferred embodiments, various monomers or other reactants are delivered to multiple reaction sites on a single substrate where they are reacted in parallel.

35 According to a preferred embodiment of the invention, a series of channels, grooves, or spots are formed on or adjacent a substrate. Reagents are selectively flowed through or deposited in the channels, grooves, or spots, forming an array having different compounds - and in some embodiments, classes of compounds - at
40 selected locations on the substrate.

 According to the first specific aspect of the invention, a block having a series of channels, such as grooves, on a surface thereof is utilized. The block is placed in contact with a derivatized glass or other substrate. In a first step, a pipettor or other
45 delivery system is used to flow selected reagents to one or more of a

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series of apertures connected to the channels, or place reagents in the channels directly, filling the channels and "striping" the substrate with a first reagent, coupling a first group of monomers thereto. The first group of monomers need not be homogenous. For example, a monomer A may be placed in a first group of the channels, a monomer B in a second group of channels, and a monomer C in a third group of channels. The channels may in some embodiments thereafter be provided with additional reagents, providing coupling of additional monomers to the first group of monomers. The block is then translated or rotated, again placed on the substrate, and the process is repeated with a second reagent, coupling a second group of monomers to different regions of the substrate. The process is repeated until a diverse set of polymers of desired sequence and length is formed on the substrate. By virtue of the process, a number of polymers having diverse monomer sequences such as peptides or oligonucleotides are formed on the substrate at known locations.

According to the second aspect of the invention, a series of microchannels or microgrooves are formed on a substrate, along with an appropriate array of microvalves. The channels and valves are used to flow selected reagents over a derivatized surface. The microvalves are used to determine which of the channels are opened for any particular coupling step.

Accordingly, one embodiment of the invention provides a method of forming diverse polymer sequences on a single substrate, the substrate comprising a surface with a plurality of selected regions. The method includes the steps of forming a plurality of channels adjacent the surface, the channels at least partially having a wall thereof defined by a portion of the selected regions; and placing selected reagents in the channels to synthesize polymer sequences at the portion of the selected regions, the portion of the selected regions comprising polymers with a sequence of monomers different from polymers in at least one other of the selected regions. In alternative embodiments, the channels or flow paths themselves constitute the selected reaction regions. For example, the substrate may be a series of adjoining parallel channels, each having reaction sites therein.

According to a third aspect of the invention, a substrate is provided which has an array of discrete reaction regions separated from one another by inert regions. In one embodiment, a first monomer solution is spotted on a first set of reaction regions of a suitably derivatized substrate. Thereafter, a second monomer solution is spotted on a second set of regions, a third monomer solution is spotted on a third set and so on, until a number of the regions each have one species of monomer located therein. These monomers are reacted with the surface, and the substrate is

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5 In alternative embodiments, the polymers or other compounds of the array are delivered to the regions as complete species, and thus the above polymer synthesis steps are unnecessary.

A further understanding of the nature and advantages of the inventions herein may be realized by reference to the remaining portions of the specification and the attached drawings.

Fig. 1 is a generalized diagram illustrating the invention;

Fig. 3 is a mapping of a resulting array of polymers;

35 Fig. 5a is a top view and Fig. 5b is a cross-sectional view of a first embodiment of a device used to synthesize arrays of polymer sequences;

Figs. 7a and 7b are top views of two of two different "fanned array" channel blocks;

Fig. 8 is a cross-sectional view of a channel block and associated flow ports according to one embodiment of the invention;

Fig. 9 is a detailed cross-sectional view of the flow ports in a channel block;

Fig. 10 is a diagram of a flow system used to deliver coupling compounds and reagents to a flow cell;

5 Figs. 11a and 11b show an apparatus used to transfer a substrate from one channel block to another;

Fig. 12 is a diagram of a multichannel solid-phase synthesizer;

10 Figs. 13a and 13b illustrate alternative arrangements of the grooves in a channel block;

Fig. 14 is a schematic illustration of reaction pathways used to prepare some hydrophobic groups of the present invention;

Figs. 15a and 15b illustrate a microvalve device;

15 Figs. 16a and 16b illustrate an alternative embodiment of the invention;

Fig. 17 is a mapping of expected fluorescent intensities with a substrate selectively exposed to fluorescent dye;

Fig. 18 is a mapping of actual fluorescence intensity versus location;

20 Fig. 19 is a mapping of fluorescence intensity versus location on a slide having four different peptides synthesized thereon;

Fig. 20 is a mapping of fluorescence intensity versus location indicating fluorescein binding on 400 micron wide photolyzed regions perpendicular to 100 micron flow paths;

25 Fig. 21 is a mapping of fluorescence intensity versus location for a substrate containing octanucleotides, heptanucleotides, and hexanucleotides and incubated with an oligonucleotide complimentary to the octanucleotide; and

30 Fig. 22 is a magnified version of Fig. 21.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

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20 I. Glossary

The following terms are intended to have the following general meanings as they are used herein:

1. Ligand: A ligand is a molecule that is recognized by a
25 receptor. Examples of ligands that can be investigated by this invention include, but are not restricted to, agonists and antagonists for cell membrane receptors, toxins and venoms, viral epitopes, hormones, opiates, steroids, peptides, enzyme substrates, cofactors, drugs, lectins, sugars,
30 oligonucleotides, nucleic acids, oligosaccharides, and proteins.
2. Monomer: A monomer is a member of the set of small molecules
35 which are or can be joined together to form a polymer or a compound composed of two or more members. The set of monomers includes but is not restricted to, for example, the set of common L-amino acids, the set of D-amino acids, the set of synthetic and/or natural amino acids, the set of nucleotides and the set of pentoses and hexoses. The particular ordering
40 of monomers within a polymer is referred to herein as the "sequence" of the polymer. As used herein, monomers refers to any member of a basis set for synthesis of a polymer. For example, dimers of the 20 naturally occurring L-amino acids form a basis set of 400 monomers for synthesis of polypeptides.
45 Different basis sets of monomers may be used at successive

steps in the synthesis of a polymer. Furthermore, each of the sets may include protected members which are modified after synthesis. The invention is described herein primarily with regard to the preparation of molecules containing sequences of monomers such as amino acids, but could readily be applied in the preparation of other polymers. Such polymers include, for example, both linear and cyclic polymers of nucleic acids, polysaccharides, phospholipids, and peptides having either α -, β -, or ω -amino acids, heteropolymers in which a known drug is covalently bound to any of the above, polynucleotides, polyurethanes, polyesters, polycarbonates, polyureas, polyamides, polyethyleneimines, polyarylene sulfides, polysiloxanes, polyimides, polyacetates, or other polymers which will be apparent upon review of this disclosure. Such polymers are "diverse" when polymers having different monomer sequences are formed at different predefined regions of a substrate. Methods of cyclization and polymer reversal of polymers are disclosed in copending application Serial No. 796,727, filed November 22, 1991, entitled "POLYMER REVERSAL ON SOLID SURFACES," incorporated herein by reference for all purposes.

3. Peptide: A peptide is a polymer in which the monomers are alpha amino acids and are joined together through amide bonds, alternatively referred to as a polypeptide. Amino acids may be the L-optical isomer or the D-optical isomer. Peptides are two or more amino acid monomers long and are often more than 20 amino acid monomers long. Standard abbreviations for amino acids are used (e.g., P for proline). These abbreviations are included in Stryer, Biochemistry, Third Ed., 1988, which is incorporated herein by reference for all purposes.

4. Receptor: A receptor is a molecule that has an affinity for a ligand. Receptors may be naturally-occurring or manmade molecules. They can be employed in their unaltered state or as aggregates with other species. Receptors may be attached, covalently or noncovalently, to a binding member, either directly or via a specific binding substance. Examples of receptors which can be employed by this invention include, but are not restricted to, antibodies, cell membrane receptors, monoclonal antibodies and antisera reactive with specific antigenic determinants, viruses, cells, drugs, polynucleotides, nucleic acids, peptides, cofactors, lectins, sugars, polysaccharides, cellular membranes, and organelles. Receptors are sometimes referred to in the art as anti-ligands. As the

term receptors is used herein, no difference in meaning is intended. A "Ligand Receptor Pair" is formed when two molecules have combined through molecular recognition to form a complex.

Specific examples of receptors which can be investigated by this invention include but are not restricted to:

- a) Microorganism receptors: Determination of ligands that bind to microorganism receptors such as specific transport proteins or enzymes essential to survival of microorganisms would be a useful tool for discovering new classes of antibiotics. Of particular value would be antibiotics against opportunistic fungi, protozoa, and bacteria resistant to antibiotics in current use.
- b) Enzymes: For instance, a receptor can comprise a binding site of an enzyme such as an enzyme responsible for cleaving a neurotransmitter; determination of ligands for this type of receptor to modulate the action of an enzyme that cleaves a neurotransmitter is useful in developing drugs that can be used in the treatment of disorders of neurotransmission.
- c) Antibodies: For instance, the invention may be useful in investigating a receptor that comprises a ligand-binding site on an antibody molecule which combines with an epitope of an antigen of interest; determining a sequence that mimics an antigenic epitope may lead to the development of vaccines in which the immunogen is based on one or more of such sequences or lead to the development of related diagnostic agents or compounds useful in therapeutic treatments such as for autoimmune diseases (e.g., by blocking the binding of the "self" antibodies).
- d) Nucleic Acids: Sequences of nucleic acids may be synthesized to establish DNA or RNA binding sequences that act as receptors for synthesized sequence.
- e) Catalytic Polypeptides: Polymers, preferably antibodies, which are capable of promoting a chemical reaction involving the conversion of one or more reactants to one or more products. Such polypeptides generally include a binding site specific for at least one reactant or reaction intermediate and an active functionality proximate to the binding site, which functionality is capable of chemically modifying the bound reactant. Catalytic polypeptides and others are described in, for example, PCT Publication No. W 90/05746,

WO 90/05749, and WO 90/05785, which are incorporated herein by reference for all purposes.

f) Hormone receptors: Determination of the ligands which bind with high affinity to a receptor such as the receptors for insulin and growth hormone is useful in the development of, for example, an oral replacement of the daily injections which diabetics must take to relieve the symptoms of diabetes or a replacement for growth hormone. Other examples of hormone receptors include the vasoconstrictive hormone receptors; determination of ligands for these receptors may lead to the development of drugs to control blood pressure.

g) Opiate receptors: Determination of ligands which bind to the opiate receptors in the brain is useful in the development of less-addictive replacements for morphine and related drugs.

5. Substrate: A material having a rigid or semi-rigid surface. In many embodiments, at least one surface of the substrate will be substantially flat, although in some embodiments it may be desirable to physically separate synthesis regions for different polymers with, for example, wells, raised regions, etched trenches, or the like. In some embodiments, the substrate itself contains wells, trenches, flow through regions, etc. which form all or part of the synthesis regions. According to other embodiments, small beads may be provided on the surface, and compounds synthesized thereon may be released upon completion of the synthesis.

6. Channel Block: A material having a plurality of grooves or recessed regions on a surface thereof. The grooves or recessed regions may take on a variety of geometric configurations, including but not limited to stripes, circles, serpentine paths, or the like. Channel blocks may be prepared in a variety of manners, including etching silicon blocks, molding or pressing polymers, etc.

7. Protecting Group: A material which is bound to a monomer unit and which may be selectively removed therefrom to expose an active site such as, in the specific example of an amino acid, an amine group. Specific examples of photolabile protecting groups are discussed in Fodor et al., PCT Publication No. WO 92/10092 (previously incorporated by reference) and U.S. Serial No. _____ filed November 2, 1992 (attorney docket No. 11509-68) incorporated herein by reference for all purposes.

8. Predefined Region: A predefined region is a localized area on a substrate which is, was, or is intended to be used for formation of a selected polymer and is otherwise referred to herein in the alternative as "reaction" region, a "selected" region, or simply a "region." The predefined region may have any convenient shape, e.g., circular, rectangular, elliptical, wedge-shaped, etc. In some embodiments, a predefined region and, therefore, the area upon which each distinct polymer sequence is synthesized is smaller than about 1 cm^2 , more preferably less than 1 mm^2 , and still more preferably less than 0.5 mm^2 . In most preferred embodiments the regions have an area less than about $10,000 \text{ }\mu\text{m}^2$ or, more preferably, less than $100 \text{ }\mu\text{m}^2$. Within these regions, the polymer synthesized therein is preferably synthesized in a substantially pure form.
9. Substantially Pure: A polymer is considered to be "substantially pure" within a predefined region of a substrate when it exhibits characteristics that distinguish it from other predefined regions. Typically, purity will be measured in terms of biological activity or function as a result of uniform sequence. Such characteristics will typically be measured by way of binding with a selected ligand or receptor. Preferably the region is sufficiently pure such that the predominant species in the predefined region is the desired sequence. According to preferred aspects of the invention, the polymer is at least 5% pure, more preferably more than 10% to 20% pure, more preferably more than 80% to 90% pure, and most preferably more than 95% pure, where purity for this purpose refers to the ratio of the number of ligand molecules formed in a predefined region having a desired sequence to the total number of molecules formed in the predefined region.

II. General

The invention can be used in variety of applications. For example, the invention can be used as a synthesis tool (as for example in peptide syntheses), as a screening tool (as for example in screening compound libraries for drug activity), or as a monitoring/diagnostic tool (as for example in medical or environmental testing). In one specific embodiment, the invention is used for nucleic acid-based diagnostics.

As a synthesis tool, the present invention provides for the formation of arrays of large numbers of different polymer sequences. According to a preferred embodiment, the invention provides for the synthesis of an array of different peptides or

oligonucleotides in selected regions of a substrate. Such substrates having the diverse sequences formed thereon may be used in, for example, screening studies to evaluate their interaction with receptors such as antibodies and nucleic acids. For example, in preferred embodiments the invention provides for screening of peptides to determine which if any of a diverse set of peptides has a strong binding affinity with a receptor and, in most preferred embodiments, to determine the relative binding affinity of various peptides with a receptor of interest.

Such diverse polymer sequences are preferably synthesized on a single substrate. By synthesizing the diverse polymer sequences on a single substrate, processing of the sequences to evaluate characteristics such as relative binding affinity is more easily conducted. By way of example, when an array of peptide sequences (or a library of other compounds) is to be evaluated to determine the peptides' relative binding affinity to a receptor, the entire substrate and, therefore, all or a group of the polymer sequences may be exposed to an appropriately labelled receptor and evaluated simultaneously.

In some embodiments, the present invention can be employed to localize and, in some cases, immobilize vast collections of synthetic chemical compounds or natural product extracts. In such methods, compounds are deposited on predefined regions of a substrate. The reaction of the immobilized compound (or compounds) with various test compositions such as the members of the chemical library or a biological extract are tested by dispensing small aliquots of each member of the library or extract to a different region. Competitive assays or other well-known techniques can be used to identify a desired activity. As an example, a large collection of human receptors is deposited on a substrate, one in each region to form an array. A plant/animal extract is then screened for binding to various receptors of the array.

The present invention has certain features in common with the "light directed" methods described in U.S. Patent No. 5,143,854, previously incorporated by reference. The light directed methods discussed in the '854 patent involve activating predefined regions of the substrate and then contacting the substrate with a preselected monomer solution. The predefined regions can be activated with a light source shown through a mask (much in the manner of photolithography techniques used in integrated circuit fabrication). Other regions of the substrate remain inactive because they are blocked by the mask from illumination. Thus, a light pattern defines which regions of the substrate react with a given monomer. By repeatedly activating different sets of predefined regions and contacting different monomer solutions with the substrate, a diverse

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array of polymers is produced on the substrate. Of course, other steps such as washing unreacted monomer solution from the substrate can be used as necessary.

In the present invention, a mechanical device or physical structure defines the regions which are available to react with a given monomer. In some embodiments, a wall or other physical barrier is used to block a given monomer solution from contacting any but a few selected regions of a substrate. In other embodiments, the amount of the monomer (or other) solution deposited and the composition of the substrate act to separate different monomer solutions on the substrate. This permits different monomers to be delivered and coupled to different regions simultaneously (or nearly simultaneously) and reduces the number of separate washing and other reaction steps necessary to form an array of polymers. Further, the reaction conditions at different activated regions can be controlled independently. Thus, the reactant concentrations and other parameters can be varied independently from reaction site to reaction site, to optimize the procedure.

In alternative preferred embodiments of the present invention, light or another activator is used in conjunction with the physical structures to define reaction regions. For example, a light source activates various regions of the substrate at one time and then a mechanical system directs monomer solutions to different activated regions, in parallel.

III. Methods for Mechanical Delivery of Reagents

In preferred embodiments of the present invention, reagents are delivered to the substrate by either (1) flowing within a channel defined on predefined regions or (2) "spotting" on predefined regions. However, other approaches, as well as combinations of spotting and flowing, may be employed. In each instance, certain activated regions of the substrate are mechanically separated from other regions when the monomer solutions are delivered to the various reaction sites.

A typical "flow channel" method of the present invention can generally be described as follows. Diverse polymer sequences are synthesized at selected regions of a substrate by forming flow channels on a surface of the substrate through which appropriate reagents flow or in which appropriate reagents are placed. For example, assume a monomer "A" is to be bound to the substrate in a first group of selected regions. If necessary, all or part of the surface of the substrate in all or a part of the selected regions is activated for binding by, for example, flowing appropriate reagents through all or some of the channels, or by washing the entire substrate with appropriate reagents. After placement of a channel

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small quantities of them in selected regions. In some steps, of course, the entire substrate surface can be sprayed or otherwise coated with a solution. In preferred embodiments, a dispenser moves from region to region, depositing only as much monomer as necessary at each stop. Typical dispensers include a micropipette to deliver the monomer solution to the substrate and a robotic system to control the position of the micropipette with respect to the substrate. In other embodiments, the dispenser includes a series of tubes, a manifold, an array of pipettes, or the like so that various reagents can be delivered to the reaction regions simultaneously.

IV. Flow Channel Embodiments

Fig. 1 illustrates an example of the invention. In this particular example, monomers and dimers of the monomer group A, B, C, and D are to be bound at selected regions of the substrate. The substrate may be biological, nonbiological, organic, inorganic, or a combination of any of these, existing as particles, strands, precipitates, gels, sheets, tubing, spheres, containers, capillaries, pads, slices, films, plates, slides, etc. The substrate may have any convenient shape, such as a disc, square, sphere, circle, etc. The substrate is preferably flat but may take on a variety of alternative surface configurations. For example, the substrate may contain raised or depressed regions on which the synthesis takes place.

The substrate and its surface form a support on which to carry out the reactions described herein. These monomers are bound using first flow channel paths x_1 , x_2 , x_3 , and x_4 which are formed or placed on or adjacent the substrate in a first orientation, and second flow channel paths y_1 , y_2 , y_3 , and y_4 which are formed or placed on or adjacent the substrate in a second orientation. The second flow channel paths intersect at least a part of the first flow channel paths. The flow channels are formed according to techniques which are described in greater detail elsewhere herein.

Initially the substrate is subjected to one or more preliminary treatments such as, for example, cleaning and the optional placement of "linker" molecules on the surface thereof. The substrate may also be provided with various active groups, common monomer sequences which will form a part of the polymers, or the like.

Thereafter, in a first coupling step, one or more of the flow channels are provided with the first monomer A, which binds through covalent bonds or otherwise to the substrate (directly or indirectly) where the flow channel contacts the substrate. In the particular example shown in Fig. 1, the flow channels x_1 and x_2 are utilized, binding the monomer A to the substrate along the entire

length of the substrate adjacent to the x_1 and x_2 channels. Each coupling step may in some embodiments be composed of a variety of substeps. For example, each coupling step may include one or more substeps for washing, chemical activation, or the like.

Thereafter or concurrently therewith, as shown in Fig. 2, a second monomer B is provided to selected flow channels and the monomer B binds to the substrate where the second flow channels provide contact therewith. In the particular example shown in Fig. 2, monomer B is bound along channels x_3 and x_4 . When the monomers A and B flow through their respective flow channels simultaneously, only a single process step is required to perform two coupling steps simultaneously. As used herein, a "process step" refers to the injection of one or more channels with one or more reagents. A "coupling step" refers to the addition of a monomer in a polymer.

Processing thereafter continues in a similar manner with monomers C and D in the manner shown in the flow diagram of Fig. 2, with monomer C being bound in the flow channels y_1 and y_2 , and D being bound in the flow channels y_3 and y_4 . Preferably, monomers C and D are directed through the flow channels y_1 to y_4 simultaneously whereby two coupling steps are performed with a single process step. Light regions in Fig. 1 indicate the intersections of the resulting flow paths.

Fig. 3 illustrates the mapping of sequences formed using the above illustrated steps. As shown therein, the sequences A, B, C, D, AD, BD, AC, and BC have been formed using only two process steps. Accordingly, it is seen that the process provides for the synthesis of vast arrays of polymer sequences using only a relatively few process steps. By way of further example, it is necessary to use only two process steps to form all of the $4^2 = 16$ dimers of a four-monomer basis set. By way of further example, to form all 4^4 octomers of a four-monomer basis set, it is necessary to provide only 256 flow channels oriented in the "x" direction, and 256 flow channels oriented in the "y" direction, with a total of eight coupling steps.

The power of the technique is further illustrated by synthesizing the complete array of six hexamer peptides from a 20 amino acid basis set. This array will include 20^6 or 64,000,000 regions defining 64,000,000 different peptides and can be formed in only six process steps. Further, the method requires only three different templates, one having 20 parallel channels, a second having 400 channels each 1/20th as wide as the first, and a third having 8000 channels each 1/20th as wide as the second. Each template will be used in two process steps, each at an orientation at 90 degrees with respect to the other as illustrated in Fig. 4. With the first

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template, the substrate is activated and then solutions of each of the 20 amino acid basis set (or other 20 member basis set) are flowed over and reacted on a different predefined stripe in a first orientation. This is the first process step and includes 20 coupling or attachment steps, which can be performed simultaneously. Next, the entire substrate is again activated and the first template is placed in a second orientation, perpendicular to the first (Fig. 4a). The 20 amino acid solutions are then flowed along 20 new predefined stripes (each perpendicular to the original set of stripes). In each of these two process steps, the 20 predefined regions (the stripes along the flow channels) are first activated and then contacted with the individual monomers so that all 20 stripes are reacted before the next activation step is necessary. In other words, 20 coupling steps are conducted in parallel, greatly reducing the number of necessary activation steps.

The four remaining coupling steps employ the second and third templates. In the third and fourth process steps (Fig. 4b), 20 channels are devoted to each monomer, and in the fifth and sixth process steps (Fig. 4c), 400 channels are devoted to each monomer. As with the first two steps, the entire substrate undergoes reaction during a single process step. Thus, only six process steps (requiring a total of about 24 hours) are required to produce the entire library of 64,000,000 peptide hexamers. In a different embodiment, a single template having 8000 channels to control delivery (e.g. 400 channels for each of the 20 amino acids in the first round) can produce the full library of hexamers with only a single rotation step. Thus, the present invention offers extremely rapid methods of preparing diverse polymer arrays.

Figs. 5a and 5b illustrate details of a first embodiment of a device used for performing the synthesis steps described above. In particular, Fig. 5a illustrates the device in top view, while Fig. 5b illustrates the device in cross-sectional side view. In the particular embodiment shown in Fig. 5, the device is used to synthesize polymer sequences on substrate 401. Substrate 401 is coupled to a rotating stage 403 and removably held by clamp 405 to channel block 407. Channel block 407 has etched therein a plurality of channels 409 in the form of stripes therein. Each channel is provided with a flow inlet 411 and an outlet 413. A vacuum source 415 is applied to one or more of the outlets 413, while a pipettor 417 is slidably mounted on arm 419 to deliver selected reagents from reservoir(s) 421 to selected flow inlets 411.

The details of a second preferred embodiment are shown in Figs. 6-11. Fig. 6 displays an apparatus for holding a substrate 111 in place against a channel block 109 by evenly distributing pressure over the substrate in a pressure chamber 101. Pressurized gas is

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admitted through gas pressure inlet 103 to provide clamping pressure to immobilize the substrate while fluids are flowed from fluid flow inlet 115, through channel 123, and out fluid outlet 117. The upper and lower portions of the pressure chamber housing 105 and 125 are held together by nuts 121 and bolts 104. Of course, other means such as clamps can be used to hold the pressure chamber housing portions together.

Fig. 7 illustrates preferred flow path configurations in channel blocks of the present invention. As shown in Figs. 7a, fluid delivery sites 127, 129, 131, 133, 135, and 137 are connected to channels leading to reaction region 141. A similar arrangement is shown for comparison in Fig. 7b where the orientation of the flow channels in the reaction regions is shifted by 90 degrees on a rectangular channel block. Vacuum ports 145 and 146 to an external vacuum line are provided so that substrate position is maintained during fluid flow.

The channels shown in Figs. 7a and 7b form a "fanned channel array" on channel block 139 in a manner analogous to that of the lead pattern employed in integrated circuits. This provides significantly increased separation of fluid delivery points in comparison to the high density of channels in the reaction region. In a 2 inch by 3 inch substrate, at least about a 4:1 increase in spatial separation typically can be attained by the fanned arrangement. Thus, if the channels in the reaction regions are separated by 200 microns, the delivery ports can be separated by 0.8 mm.

The spatial separation can be further increased by staggering the delivery ports as shown for ports 127, 129, and 131. This can provide an additional channel separation of at least about 3:1. Thus, for the channels separated by 200 microns, a staggered fanned array provides 2.4 mm separation between the delivery ports. Thus, fluid can be delivered to a high-density array of channels in the reaction region from standard 1.6 mm Teflon™ tubing. If additional spacing is necessary, the substrate size can be increased, while preserving the reaction region size.

As shown in Fig. 8, the fluid delivery ports are accessed from holes in the back surface of a stabilizing plate 108 on the channel block. The stabilizing plate, which is preferably made from fused pyrex, provides structural integrity to the channel block during clamping in the pressure chamber. It may also provide a means to access the channel block ports and reduce leakage between ports or channels. In preferred embodiments, the channels 123 of the channel block are formed on a wafer 106 which generally may be any machinable or cast material, and preferably may be etched silicon or a micromachined ceramic. In other embodiments, the channel block is

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steps during a chemical synthesis. One block forms a horizontal array on the solid substrate, while the other block forms a vertical array. To create a matrix of intersecting rows and columns of chemical compounds, the solid substrate is transferred from one block to the other during successive process steps. While many experiments require only a single transfer from one block to the other during a series of process steps, the fanned channel array transfer block 75 illustrated in Figs. 11a and 11b provides one device for maintaining accurate registration of the solid substrate 71 relative to the channel blocks 79 during repeated transfers. In some embodiments, a single channel block can be used for horizontal and vertical arrays by simply rotating it by 90 degrees as necessary.

The transfer block is positioned with respect to the channel block so that the dimensional characteristics of the solid substrate are not used in the alignment. The transfer block 75 is aligned to the channel block by kinematic mount 81 while vacuum is switched from vacuum line 83 on the channel block to vacuum line 77 on the transfer block (during normal operation, a vacuum holds the substrate against the channel block). The substrate and transfer block are then moved and repositioned relative to the second channel block. Vacuum is then switched to the second channel block, retaining the substrate in proper alignment. This way, accurate registration can be assured between process steps regardless of variation in the dimensions of individual substrates. The transfer block system also maintains alignment of the matrix area during transfers to and from the flow cell during experiments utilizing both mechanical and light-directed process steps.

In some embodiments the channel block need not be utilized. Instead, in some embodiments, small "strips" of reagent are applied to the substrate by, for example, striping the substrate or channels therein with a pipettor. Such embodiments bear some resemblance to the spotting embodiments of this invention. According to other embodiments the channels will be formed by depositing a photoresist such as those used extensively in the semiconductor industry. Such materials include polymethyl methacrylate (PMMA) and its derivatives, and electron beam resists such as poly(olefin sulfones) and the like (more fully described in Ghandi, "VLSI Fabrication Principles," Wiley (1983) Chapter 10, incorporated herein by reference in its entirety for all purposes). According to these embodiments, a resist is deposited, selectively exposed, and etched, leaving a portion of the substrate exposed for coupling. These steps of depositing resist, selectively removing resist and monomer coupling are repeated to form polymers of desired sequence at desired locations.

In some embodiments, a resist can be used to activate certain regions of the substrate. Certain resist materials such as acid-generating polymers, for example, will release protons upon irradiation. According to these embodiments, a substrate covered with such material is irradiated through a mask or otherwise selectively irradiated so that the irradiated regions of the substrate are exposed to acidic conditions. Acid-labile protecting group on the substrate or oligomers on the substrate are removed, leaving an activated region. At this point, all or part of the resist may be removed. In preferred embodiments, the resist will be removed only in the activated regions, so that the channels are formed at the activated regions. Alternatively, the resist can be removed from the entire substrate. In this case, a separate channel block can then be contacted with the substrate to define flow channels, or a conventional VLSIPS™ procedure can be employed.

In preferred embodiments, the substrate is conventional glass, pyrex, quartz, any one of a variety of polymeric materials, or the like. Of course, the substrate may be made from any one of a variety of materials such as silicon, polystyrene, polycarbonate, or the like. In preferred embodiments the channel block is made of silicon or polychlorotrifluorethylene, such as material known under the trade name Kelf™ 80 made by 3M, although a wide variety of materials such as polystyrene, polycarbonate, glass, elastomers such as Kalrez made by DuPont, various ceramics, stainless steel, or the like may be utilized.

The channels in the channel block are preferably made by machining, compression molding, injection molding, lithography, laser cutting, or the like depending upon the material of interest. In some embodiments employing larger channel blocks, the raised portions of the channels in the channel block are treated by lapping with lapping film (0.3 μ m grit). Such smooth surfaces provide good seals to the substrate without the use of a sealant and, therefore, without the possibility of leaving sealant material on the substrate when rotating the channel block. Preferably, all operations are conducted at substantially ambient temperatures and pressures.

A particularly preferred channel block is prepared by chemical etching of polished silicon wafers. Chemical etching is a widely used technique in integrated circuit fabrications. It can easily provide 60 or more 100 micron channels on a 12.8 mm region of a polished silicon wafer. Even after etching, the top (unetched) surface regions of the wafer retains the very flat profile of the unetched wafer. Thus, close contact with the substrate is ensured during flow cell operation.

In operation, the surface of the substrate is appropriately treated by cleaning with, for example, organic

solvents, methylene chloride, DMF, ethyl alcohol, or the like. Optionally, the substrate may be provided with appropriate linker molecules on the surface thereof. The linker molecules may be, for example, aryl acetylene, ethylene glycol oligomers containing from 2-10 monomers or more, diamines, diacids, amino acids, or combinations thereof. Thereafter, the surface is provided with protected surface active groups such as TBOC or FMOC protected amino acids. Such techniques are well known to those of skill in the art.

Thereafter, the channel block and the substrate are brought into contact forming fluid-tight channels bounded by the grooves in the channel block and the substrate. When the channel block and the substrate are in contact, a protecting group removal agent is, thereafter, directed through a first selected channel or group of channels by placing the pipettor on the flow inlet of the selected channel and, optionally, the vacuum source on the outlet of the channel. In the case of, for example, TBOC protected amino acids, this protecting group removal agent may be, for example, trifluoroacetic acid (TFA). This step is optionally followed by steps of washing to remove excess TFA with, for example, dichloromethane (DCM).

Thereafter, a first amino acid or other monomer A is directed through the first selected flow channel. Preferably this first amino acid is also provided with an appropriate protecting group such as TBOC, FMOC, NVOC, or the like. This step is also followed by appropriate washing steps. The of deprotection/coupling steps employed in the first group of channels are concurrently with or thereafter repeated in additional groups of channels. In preferred embodiments, monomer A will be directed through the first group of channels, monomer B will be directed through a second group of flow channels, etc., so that a variety of different monomers are coupled on parallel channels of the substrate.

Thereafter, the substrate and the channel block are separated and, optionally, the entire substrate is washed with an appropriate material to remove any unwanted materials from the points where the channels contact the substrate.

The substrate and/or block is then, optionally, washed and translated and/or rotated with the stage. In preferred embodiments, the substrate is rotated 90 degrees from its original position, although some embodiments may provide for greater or less rotation, such as from 0 to 180 degrees. In other embodiments, such as those discussed in connection with the device shown in Fig. 7, two or more different channel blocks are employed to produce different flow patterns across the substrate. When the channel block is rotated, it may simultaneously be translated with respect to the substrate. "Translated" means any relative motion of the substrate

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filled with resin or reaction mixture. The gasketing allows close contact between the support matrix 1002 and a "mask" (not shown). The mask serves to control delivery of a first group reactant solutions through predetermined lines (tubes) to a first set of reaction regions. By ensuring close contact between the delivery tubes 1000, the mask, and the support matrix 1002, the probability that reaction solutions will be accidentally added to the wrong reaction site is reduced.

After each process step, the mask can be changed so that a new group reactants is delivered to a new set of reaction regions. In this manner, a combinatorial strategy can be employed to prepare a large array of polymers or other compounds. In other embodiments, mechanisms other than masks can be employed to block the individual delivery tubes. For example, an array of control valves within the tubes may be suitable for some embodiments.

By adjusting the thickness of the synthesis support matrix, the quantity of immobilized material in the reaction regions can be controlled. For example, relatively thin support synthesis matrices can be used to produce small amounts of surface bound oligomers for analysis, while thicker support matrices can be used to synthesize relatively large quantities of oligomers which can be cleaved from the support for further use. In the latter embodiment, a collector having dimensions matching the individual synthesis supports can be employed to collect oligomers that are ultimately freed from the reaction matrix.

To illustrate the ability of this system to synthesize numerous polymers, a square synthesis matrix measuring 10 cm along each side and having 5 mm reaction regions separated by 5 mm wide gaskets provides 100 individual syntheses sites (reaction regions). By reducing the size of the reaction regions to 2.5 mm on each side, 400 reactions regions become available.

While linear grooves are shown herein in the preferred aspects of the invention, other embodiments of the invention will provide for circular rings or other shapes such as circular rings with radial grooves running between selected rings. According to some embodiments, channel blocks with different geometric configurations will be used from one step to the next, such as circular rings in one step and linear stripes in the next. Fig. 13a illustrates one of the possible arrangements in which the channels 409 are arranged in a serpentine arrangement in the channel block 407. Through appropriate translation and/or rotation of the channel block, polymers of desired monomer sequence are formed at the intersection of the channels during successive polymer additions, such as at location 501, where the intersection of a previous or subsequent set of channels is shown in dashed lines. Fig. 13b

5 In some embodiments of the invention, the various reagents, such as those containing the various monomers, are not pumped through the apertures 413. Instead, the reagent is placed in one of the grooves, such as the grooves 409 shown in Fig. 13b, filling the groove. The substrate is then placed on top of the channel block, and the exposed portions of the substrate are permitted to react with the materials in the grooves. In preferred 10 embodiments, the channels are of the same width as the raised regions between the channels. According to these embodiments, the substrate may then be moved laterally by one channel width or an integer multiple of a channel width, permitting reaction with and placement 15 of monomers on the regions between the channels in a previous coupling step. Thereafter, the substrate or channel block will be rotated for the next series of coupling steps.

provide more than 10 different polymer sequences on the surface of the substrate. In more preferred embodiments, the process is repeated to provide more than 10^2 , 10^3 , 10^4 , 10^5 , 10^6 , or more polymer sequences on a single substrate. In some embodiments the process is repeated to provide polymers with as few as two monomers, although the process may be readily adapted to form polymers having 3, 4, 5, 6, 10, 15, 20, 30, 40, 50, 75, 100 or more monomers therein.

According to preferred embodiments, the array of polymer sequences is utilized in one or more of a variety of screening processes, one of which is described in copending application U.S. Serial No. 796,947, filed on November 22, 1991 and incorporated herein by reference for all purposes. For example, according to one embodiment, the substrate is then exposed to a receptor of interest such as an enzyme or antibody. According to preferred embodiments, the receptor is labelled with fluorescein, or otherwise labelled, so as to provide for easy detection of the location at which the receptor binds. According to some embodiments, the channel block is used to direct solutions containing a receptor over a synthesized array of polymers. For example, according to some embodiments the channel block is used to direct receptor solutions having different receptor concentrations over regions of the substrate.

According to most preferred embodiments, amplification of the signal provided by way of fluorescein labelling is provided by exposing the substrate to the antibody of interest, and then exposing the substrate to a labelled material which is complementary to the antibody of interest and which preferably binds at multiple

locations of the antibody of interest. For example, in one specific embodiment, if a mouse antibody is to be studied, a labelled second antibody may be exposed to the substrate which is, for example, goat antimouse. Such techniques are described in PCT Publication No. WO92/10092, previously incorporated herein by reference.

V. Spotting Embodiments

According to some embodiments, monomers (or other reactants) are deposited from a dispenser in droplets that fill predefined regions. For example, in a single coupling step, the dispenser deposits a first monomer in a series of predefined regions by moving over a first region, dispensing a droplet, moving to a second region, dispensing a droplet, and so on until the each of the selected regions has received the monomer. Next the dispenser deposits a second monomer in a second series of predefined regions in much the same manner. In some embodiments, more than one dispenser may be used so that more than one monomer are simultaneously deposited. The monomers may react immediately on contact with the reaction regions or may require a further activation step, such as the addition of catalyst. After some number of monomers have been deposited and reacted in predefined regions throughout the substrate, the unreacted monomer solution is removed from the substrate. This completes a first process step.

For purposes of this embodiment, the spacing between the individual reaction regions of the substrate preferably will be less than about 3 mm, and more preferably between about 5 and 100 μm . Further, the angular relation between the regions is preferably consistent to within 1 degree and more preferably to within 0.1 degree. Preferably, the substrate will include at least about 100 reaction regions, more preferably at least about 1000 reaction regions, and most preferably at least about 10,000 reaction regions. Of course, the density of reaction regions on the substrate will vary. In preferred embodiments, there are at least about 1000 reaction regions per cm^2 of substrate, and more preferably at least about 10,000 regions per cm^2 .

To deposit reactant droplets consistently at precisely specified regions, a frame of reference common to the delivery instrument and the substrate is required. In other words, the reference coordinates of the instrument must be accurately mapped onto the reference coordinates of the substrate. Ideally, only two reference points on the substrate are necessary to map the array of polymer regions completely. The dispenser instrument locates these reference points and then adjusts its internal reference coordinates to provide the necessary mapping. After this, the dispenser can move a particular distance in a particular direction and be positioned

5 Unfortunately, pressing or other mechanical operations commonly encountered during fabrication and use of a substrate can warp the substrate such that the correspondence between the reference marks and the reaction regions is altered.

In order to locate the appropriate reference point initially and align the dispenser with respect to it, a vision or blind system may be employed. In a vision system, a camera is rigidly mounted to the dispenser nozzle. When the camera locates the reference point(s), the dispenser is known to be a fixed distance and direction away from the point, and a frame of reference is established. Blind systems of the present invention locate the reference point(s) by capacitive, resistive, or optical techniques, for example. In one example of an optical technique, a laser beam is transmitted through or reflected from the substrate. When the beam encounters a reference mark, a change in light intensity is detected by a sensor. Capacitive and resistive techniques are similarly applied. A sensor registers a change in capacitance or resistivity when a reference point is encountered.

Starting at a single reference point, the dispenser is translated from one reaction region to other regions of the substrate by a correct distance in the correct direction (this is the "dead reckoning" navigational technique). At each stop, the dispenser

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only in terms of translational movements. However, other systems may also be employed. In one embodiment, the dispenser is aligned with respect to the region of interest by a system analogous to that employed in magnetic and optical storage media fields. For example, the region in which monomer is to be deposited is identified by a track and sector location on the disk. The dispenser is then moved to the appropriate track while the disk substrate rotates. When the appropriate cell is positioned below the dispenser (as referenced by the appropriate sector on the track), a droplet of monomer solution is released.

Control of the droplet size may be accomplished by various techniques. For example, in one embodiment, a conventional micropipetting instrument is adapted to dispense droplets of five nanoliters or smaller from a capillary. Such droplets fit within regions having diameters of 300 μm or less when a non-wetting mask of the invention is employed.

In another embodiment, the dispenser is a piezoelectric pump that generates charged droplets and guides them to the reaction region by an electric field in a manner analogous to conventional ink-jet printers. In fact, some ink-jet printers can be used with minor modification by simply substituting a monomer containing solution for ink. For example, Wong *et al.*, European Patent Application 260 965, incorporated herein by reference for all purposes, describes the use of a commercial printer to apply an antibody to a solid matrix. In the process, a solution containing the antibody is forced through a small bore nozzle that is vibrating in a manner that fragments the solution into discrete droplets. The droplets are subsequently charged by passing through an electric field and then deflected onto the matrix material.

A conventional ink drop printer includes a reservoir in which ink is held under pressure. The ink reservoir feeds a pipe which is connected to a nozzle. An electromechanical transducer is employed to vibrate the nozzle at some suitable high frequency. The actual structure of the nozzle may have a number of different constructions, including a drawn glass tube which is vibrated by an external transducer, or a metal tube vibrated by an external transducer (e.g. a piezoelectric crystal) or a magnetostrictive metal tube which is magnetostrictively vibrated. The ink accordingly is ejected from the nozzle in a stream which shortly thereafter breaks into individual drops. An electrode may be present near the nozzle to impart a charge to the droplets. Conventional ink drop dispensers are described in U.S. Patent Nos. 3,281,860 and 4,121,222, which are incorporated by reference herein for all purposes.

In a different preferred embodiment, the reactant solutions are delivered from a reservoir to the substrate by an

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pressure is applied to the extract solution by solvent molecules diffusing across the bag to equalize a concentration difference. The extract is thus forced out of a nozzle in the bag at a constant rate. Cell sorters are also well-known in the art, and can be used in applications where it is desirable to apply single biological cells to distinct locations on the substrate.

Although the above embodiments have been directed to systems employing liquid droplets, minuscule aliquots of each test substance can also be delivered to the cell as miniature pellets. Such pellets can be formed from the compound of interest (e.g. ligands for use in an affinity assay) and one or more kinds of inert binding material. The composition of such binders and methods for the preparation of the pellets will be apparent to those of skill in the art. Such "mini-pellets" will be compatible with a wide variety of test substances, stable for long periods of time, suitable for easy withdrawal from the storage vessel and dispensing (i.e., non-tacky, preferably suspendable in a liquid such as physiological buffer), and inert with respect to the binding activity of receptors.

In preferred embodiments, the reactant solutions in each predefined region are prevented from moving to adjacent regions by appropriate barriers or constraining regions. For example to confine aqueous monomer solutions, a hydrophilic material is used to coat the reaction regions, while a hydrophobic material is used in preferred embodiments to coat the region surrounding the individual reaction regions. Of course, when non-aqueous or nonpolar solvents are employed, different surface coatings are generally preferred. By choosing appropriate materials (substrates, hydrophobic coatings, and reactant solvents), the contact angle between the droplet and the substrate is advantageously controlled. Large contact angles between the reactant droplets and the substrate are desired because the solution then wets a relatively small reaction region with shallow contact angles, on the other hand, the droplet wets a larger area. In extreme cases, the droplet will spread to cover the entire surface.

The contact angle is determined by the following expression, known as Young's equation:

$$\cos \theta = (\sigma_s - \sigma_{sl}) / \sigma_l$$

where θ is the wetting angle, σ_s is the solid-air tension, σ_{sl} is the solid-liquid tension, and σ_l is the liquid-air surface tension. The values of these surface tensions are governed by thermodynamic considerations including the chemical constituents of the liquid and the solid substrate. The liquid-air surface tension for various

chemicals is easily measured by a variety of techniques such as those described in Adamson, Physical Chemistry of Surfaces, John Wiley and Sons, 5th Ed. (1990) which is incorporated herein by reference for all purposes. The difference of the solid-liquid and solid-air tensions can, for a given system, be determined empirically from a Zisman plot. In this approach, the contact angles are measured for a homologous series of liquids on a given solid surface. For some liquid in the series, a "critical contact angle" is observed, beyond which lower surface tension liquids wet the surface. The liquid-air surface tension of the liquid at this critical contact angle is assumed to be the surface tension of the solid. This approach has been found to provide quite reasonable results for low energy solids such as Teflon, polyethylene, hydrocarbons, etc. The information gained from such studies is used to optimize substrate compositions to increase wetting angles for given reactant solutions in the array.

Methods for controlling chemical composition and therefore the local surface free energy of a substrate surface include a variety of techniques apparent to those skilled in the art. Chemical vapor deposition and other techniques applied in the fabrication of integrated circuits can be applied to deposit highly uniform layers on selected regions of a surface. As a specific example, the wettability of a silicon wafer surface has been manipulated on the micrometer scale through a combination of self-assembled monolayer depositions and micromachining. See Abbott et al., "Manipulation of the Wettability of Surfaces on the .1 to 1 Micrometer Scale Through Micromachining and Molecular Self-Assembly" Science, 257 (Sept. 4, 1992) which is incorporated herein by reference for all purposes.

In a preferred embodiment, the perimeters of the individual regions are formed on a hydrophilic substrate defined by selectively removing hydrophobic protecting groups from the substrate surface. For example, a mono-layer of hydrophobic photoprotecting groups can be coupled to, for example, linker molecules attached to the substrate surface. The surface then is selectively irradiated (or otherwise activated by, for example, acid) through a mask to expose those areas where the reaction regions are to be located. This cleaves the protecting groups from the substrate surface, causing the reaction regions to be less hydrophobic than the surrounding area. This process produces a high density of reaction regions on the substrate surface. Because hydrophobic materials have lower surface free energies (surface tensions) than water, the solution droplet in the cell beads rather than spreads.

In some preferred embodiments, the substrate is prepared by first covalently attaching a monolayer of the desired reactive functional group (e.g. amine, hydroxyl, carboxyl, thio, etc.), which

is protected by a hydrophobic photolabile protecting moiety. If the substrate provides a glass surface, the monolayer may be deposited by a silanation reaction as shown below

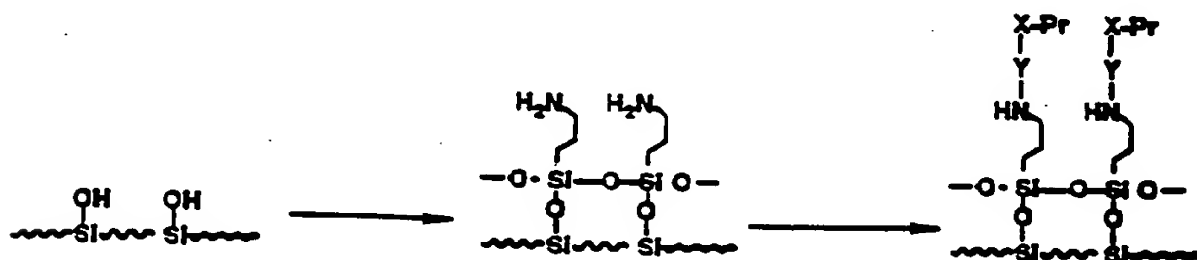


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In the above structures, Y is a spacer group such as a polymethylene chain, X is a reactive protected group such as NH, C(O)O, O, S, etc., and Pr is a hydrophobic photolabile protecting group.

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In an alternative preferred embodiment shown below, the substrate surface is first derivatized by, for example, a silanation reaction with appropriates to provide an amine layer. A molecule including a spacer, a reactive group, and a photolabile group is then coupled to the surface.



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The photolabile protecting group should be sufficiently hydrophobic as to render the substrate surface substantially non-wettable. Removal of the protecting group in specific areas by exposure to light through a suitable mask, liberates the reactive functional groups. Because these groups are hydrophilic in character, they will render the substrate wettable in the exposed regions.

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The class of nitrobenzyl protecting groups, which is exemplified by the nitroveratryl group, imparts significant

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In still other embodiments, the reaction regions are three-dimensional areas defined by, for example, gaskets or dimples on the substrate surface. The dimples or gaskets may also act as identification marks directing the dispenser to the region of interest.

If the solvent (or other liquid used to deliver the reactant) has a sufficiently high vapor pressure, evaporation can cause the reactant concentration to increase. If left unchecked, this process ultimately causes the solute to precipitate from solution. The effects of evaporation can be minimized by sealing selected regions of the substrate when they need not be accessible. Alternatively, the partial pressure of volatile reagents can be adjusted so that the liquid and vapor phase fugacities are equalized and the thermodynamic force driving evaporation is reduced. The partial pressure of the reagents may be increased by providing a relatively large reservoir of volatile reagents in a sealed chamber. For example, solvents having a low vapor pressure under the conditions of interest can be used. In some cases, evaporation can be further controlled by application of a film or coverplate having a reverse array pattern. Other methods of preventing evaporation are well-known in the physical chemical arts and may be used in the present invention.

In some preferred embodiments, evaporation is advantageously employed to accelerate hybridization of target oligonucleotides with immobilized oligonucleotides in the reaction regions. In one specific embodiment, fluorescently tagged or otherwise labelled target oligonucleotides in solution (e.g., a solution containing a salt such as ammonium acetate or magnesium chloride) are delivered to reaction regions containing immobilized probe oligonucleotides. As the volatile salt solution evaporates from the reactant droplet (in the same manner as solvent evaporates from an ink droplet deposited by an ink jet printer), a locally high concentration ratio of target to probe oligonucleotide results, accelerating hybridization. If hybridization is carried out at room temperature, ten minutes to a few hours are typically required to complete the reaction. After sufficient time, the unhybridized DNA is washed or otherwise removed from the substrate. Finally, the substrate is imaged to detect regions in which the probe and target DNA have hybridized. Of course, evaporation can be advantageously employed to increase the local concentration of non-DNA solutes in a variety of reactions besides hybridization. For example in some embodiments, receptor solutions are sufficiently volatile that the local receptor concentration increases in the reaction regions containing peptides, for example, to be screened.

The arrays produced according to the above spotting embodiments are generally used in much the same manner as the arrays produced by the flow channel embodiments described above. For example, the arrays can be used in screening with fluorescein labelled receptors as described in PCT Publication No. WO92/10092, previously incorporated by reference.

VI. Alternative Embodiments

According to some embodiments of the invention, microvalve structures are used to form channels along selected flow paths on the substrate. According to these embodiments, an array of microvalves is formed and operated by an overlying or underlying array of electrodes that is used to energize selected valves to open and close such valves.

Fig. 15 illustrates such a structure, Fig. 15a illustrating the system in end view cross-section and Fig. 15b illustrating the system in top view. The structure shown therein provides for only two synthesis chambers for the purpose of clarity, but in most embodiments a far greater number of chambers will be provided. Microvalves are discussed in detail in, for example, Zdeblick, U.S. Patent No. 4,966,646, and Knutti, "Advanced Silicon Microstructures," ASICT Conference (1989), both incorporated herein by reference for all purposes.

As shown therein, a substrate 602 is provided with a plurality of channels 604 formed using photolithographic, or other related techniques. The channels lead up to a synthesis chamber 606. At the end of each channel is valve structure 608. As shown in Fig. 15, the channels lead up to the chambers, but may be isolated from the chambers by the valves. Multiple valves may be provided for each chamber. In the particular structure shown in Fig. 15, the right valve on the left chamber and the left valve on the right chamber are open while the remaining valves are closed. Accordingly, if reagent is delivered to the top of the substrate, it will flow through the open channel to and through the chamber on the left, but not the one on the right. Accordingly, coupling steps may be conducted on the chamber with selected reagents directed to selected chambers, using the techniques discussed above.

According to some embodiments, a valve is supplied on one side of the chamber 606, but the valve on the opposite side is replaced by a semi-permeable membrane. According to these embodiments, it becomes possible to flow a selected reagent into the chamber 606 and, thereafter, flow another selected reagent through the flow channel adjacent the semi-permeable membrane. The semi-permeable membrane will permit a portion of the material on one side

or the other to pass through the membrane. Such embodiments will be useful in, for example, cell studies.

Screening will be performed by, for example, separating or cutting two halves of the device, enabling screening by, for example, contacting with a fluorescein labelled antibody, or the like followed by photodetection.

Figs. 16a and 16b illustrate another alternative embodiment of the invention which combines the mechanical polymer synthesis techniques disclosed herein with light-directed synthesis techniques. According to these embodiments, a substrate 401 is irradiated in selected regions, shown as the stripes in Fig. 16a. The surface of the substrate is provided with photoremovable groups in accordance with PCT Publication No. WO92/10092 (previously incorporated by reference) on, for example, amine groups in the specific case of peptide synthesis. During this step regions 701, 702, and 703 of the substrate, among others, are deprotected, leaving remaining regions of the substrate protected by photoremovable groups such as nitroveratryl oxycarbonyl ("NVOC"). According to a specific embodiment of the invention the widths of the irradiated regions equal the widths of the protected regions of the substrate.

Thereafter, as shown in Fig. 16b the substrate is contacted with a channel block 407. In the particular embodiment shown in Fig. 16b, the channels 704, 705, and 707 are aligned with the regions 701, 702, and 703, respectively, on the substrate 401. As will be apparent, specific embodiments of the invention provide for irradiated regions and channels in the form of stripes, which are aligned during this step. Other embodiments, however, will provide for other shapes of irradiated regions and channels, and other relative orientations of the irradiated regions and channels. The channel block and substrate will be aligned with, for example, an alignment mark placed on both the substrate and the channel block. The substrate may be placed on the channel block with, for example, a vacuum tip.

Thereafter, a selected reagent is flowed through or placed in the channels in the channel block for coupling to the regions which have previously been exposed to light. As with the flow channel embodiments described above, the substrate may be placed in contact with a prefilled channel block in some embodiments to avoid compression of the channel block to the substrate and dead spots during pumping. According to preferred aspects of the invention, a different reagent flows through each of the channels 701, 702, and 703 such as, for example, a reagent containing monomers A, B, and C. The process may then, optionally, involve a second coupling step in which the substrate is translated by, e.g., one

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channel width, to provide coupling of a monomer in the regions between the original channels.

Thereafter, the process of directed irradiation by light, followed by coupling with the channel block is repeated at the previously unexposed regions. The process is then preferably repeated again, with the stripes of the mask and the channel block rotated at, for example, 90 degrees. The coupling steps will provide for the formation of polymers having diverse monomer sequences at selected regions of the substrate through appropriate translation of the mask and substrate, and through appropriate mask selection. Through a combination of the light-directed techniques and the mechanical flow channel techniques disclosed herein, greater efficiency in forming diverse sequences is achieved, because multiple monomers are coupled in a single irradiation/coupling step.

In light-directed methods, the light shown through the mask is diffracted to varying degrees around the edges of the dark regions of the mask. Thus, some undesired removal of photosensitive protecting groups at the edges of "dark" regions occurs. This effect is exacerbated by the repeated mask translations and subsequent exposures, ultimately leading to inhomogeneous synthesis sites at the edges of the predefined regions. The effect is, of course, dependent upon the thickness of the glass substrate and the angle at which the light is diffracted. If the mask is positioned on the "backside" of the substrate, a diffraction angle of 2.5° and a substrate thickness of 0.7 mm creates a 60 μm strip of light (of variable intensity) flanking each edge. For a 0.1 mm thick substrate, the strip is approximately 5 μm wide.

To reduce these "bleed-over" effects of diffraction, a pinhole mask may be employed to activate and/or define reaction regions of the substrate. Thus, for example, light shown through the pinhole mask is directed onto a substrate containing photoremovable hydrophobic groups. The groups in the illuminated regions are then removed to define hydrophilic reaction regions. In one specific embodiment, the pinhole mask contains a series of circular holes of defined diameter and separation, e.g., 20 μm diameter holes spaced 50 μm apart. In some preferred embodiments, a stationary pinhole mask is sandwiched between the substrate and a translational mask of the type described in PCT Publication No. WO92/10092. In this manner selected regions of the substrate can be activated for polymer synthesis without bleed-over. The translational mask is used to illuminate selected holes of the stationary pinhole mask, and is aligned such that its edges dissect the distance separating the holes of the stationary mask thereby eliminating diffractive removal of photoprotecting groups at neighboring sites. Because there is negligible bleed-over incident light, inhomogeneous synthesis at

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Six nucleosides were then coupled to the entire reaction region using a synthesis process consisting of deprotection, coupling, and oxidation steps for each monomer applied. These first six nucleosides were coupled in a reaction region defined by a 0.84 inch diameter circular well in an aluminum template clamped to the two by three inch slide.

The seventh and eighth monomers were applied to the substrate by flowing monomer solutions through 100 micron channels in an etched silicon channel block (employed in Example C above). The seventh base was coupled along the long axis (vertical) of the two-inch by three-inch slide, and the eighth base perpendicular to the seventh, along the short axis (horizontal) of the slide. This defined an active matrix region of 1.28 by 1.28 cm having a density of 2,500 reaction regions per square centimeter.

The channel block was centered over the reaction region and clamped to the substrate using a clamping assembly consisting of machined aluminum plates. This aligned the two inch by three inch substrate relative to the channel block in the desired orientation. Rotation of the top clamp plate and channel block relative to the bottom clamp plate and substrate between the seventh and eighth coupling steps provided for the matrix of intersecting rows and columns.

In the top clamp plate, fluid delivery wells were connected to laser-drilled holes which entered individual channels from the back surface of the channel block. These delivery wells were used to pipette coupling reagents into channels while the channel block was clamped to the substrate. Corresponding fluid-retrieval wells were connected to vacuum at the downstream of the channel block, drawing fluid through the channels and out to a waste container. Thus continuous fluid flow over the substrate in the channel region during coupling steps was achieved.

The complete octamer synthesized at the channel intersections formed by the seventh and eighth coupling steps had the following sequence:

Substrate--(3')CGCAGCCG(5') (SEQ. ID NO:4).

After completion of the synthesis process, cleavage of exocyclic amines was performed by immersion of the reaction region in concentrated ammonium hydroxide. The reaction region was then incubated at 15°C for one hour in a 10 nM solution of the complementary base sequence 5' GCGTCGGC-F (SEQ. ID No:5), where "F" is a fluorescein molecule coupled to the 3' end of the oligonucleotide. The target chain solution was then flushed from the reaction region and replaced with neat 6x SSPE buffer, also at 15°C. Finally, the reaction region was then scanned using a laser fluorescence detection system while immersed in the buffer.

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The brightest regions in the resulting image (Fig. 21) correspond to channel intersections where a full octamer was synthesized on the substrate surface. Vertical columns on the image displayed the channel regions where the seventh base was coupled, while horizontal rows display the channel regions where the eighth base was coupled. Brightness in the channel intersection regions indicated hybridization between the fluoresceinated target chain and the complementary chain synthesized and bound to the substrate in these regions. The vertical stripes of the image showed a consistent brightness with regions of significantly greater brightness at the intersection regions. The horizontal stripes did not contain the consistent brightness of the vertical stripes, but did have regions of brightness at the intersections with the vertical stripes.

The consistent brightness along the seventh monomer axis (vertical) indicated partial hybridization of the target chain in areas where seven of the eight complementary bases were coupled to the substrate surface. The lack of brightness along the eighth monomer axis (horizontal) is consistent with the expectation that a chain of six matching bases bound to the substrate surface will not hybridize effectively to an octamer in solution (heptamers with six matching bases followed by a mismatch at the seventh position). The darker background consists of hexamers consisting of the first six monomers coupled to the entire reaction region.

Fig. 22 is a magnified view of the image in Fig. 21. Fig. 22 demonstrates that the separate reaction regions are well resolved.

VII. Conclusion

The above description is illustrative and not restrictive. Many variations of the invention will become apparent to those of skill in the art upon review of this disclosure. Merely by way of example a variety of substrates, receptors, ligands, and other materials may be used without departing from the scope of the invention. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.